Exploring occupational standing activities using accelerometer-based activity monitoring

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Abstract

Prolonged standing at work is required by an estimated 60% of the employed population and is associated with a high prevalence of musculoskeletal disorders. 'Standing' is expected to encompass a range of activities of varying intensity. This study aimed to define a range of 'standing' work-based activities; and objectively explore differences between 'standing' occupations. The following movements were defined using a triaxial accelerometer (ActivPAL) through recordings of known movements (n=11): static standing, weight-shifting, shuffling, walking and sitting. Movements over a working day were defined for chefs (n=10), veterinary surgeons (n=7) and office workers (n=9). Despite veterinary surgeons and chefs spending a similar time in an upright posture, veterinary surgeons spent 62% of this time standing statically whereas chefs split their time between all the movements. Overall, this study provides the first attempt to define 'standing' activities, allowing the differentiation of activities between occupations spending similar periods of time upright.

Keywords:

Occupational Standing; Accelerometer; Activity monitor; Veterinary Surgeons; Chefs

Practitioner Summary

This study identified a range of work-based 'standing' activities of varying intensity. Differences in activity were recorded between two occupations spending a similar time in an upright posture (veterinary surgeons and chefs). A broader definition of standing activities could be important when considering factors related to musculoskeletal disorders at work.

Introduction

Prolonged standing at work is necessary for an estimated 60% of the employed population (Coenen et al., 2016; Tissot et al., 2005). There is a high prevalence of musculoskeletal disorders in occupations that demand prolonged standing, including dentists, surgical staff, nurses, chefs and sales staff with 62-90% reporting discomfort in at least one body region (Alexopoulus et al., 2004; Capodaglio, 2017; Haukka et al., 2006; Sheikhzadeh et al., 2009). This is reinforced by prospective questionnaire studies and systematic reviews identifying an association between prolonged occupational standing and musculoskeletal disorders (Andersen et al., 2007; Coenen et al., 2016; Messing et al., 2006). Prospective research has also identified an increased risk of chronic venous disorders (Tomei et al., 1999; Tüchsen et al., 2005) and heart disease (Smith et al., 2017) associated with prolonged occupational standing.

Prevalence studies predominantly rely on subjective quantification of work-based activity (Alexopoulus et al., 2004; Andersen et al., 2007; Capodaglio, 2017; Haukka et al., 2006; Messing et al., 2006; Sheikhzadeh et al., 2009; Tomei et al., 1999). Although systematic reviews have found many self-report assessments to show good repeatability, the criterion validity of these compared to objective assessments is low (Helmerhorst et al., 2012; Kwak et al., 2011), with reports that subjective measures overestimated activity (Hagstromer et al., 2010). The reliability of subjective measures has also been linked to individual characteristics including gender, education level and age (Dyrstad et al., 2014; Prince et al., 2008).

Objective measures of work place activity are limited, particularly in jobs that are on their feet all day. Whilst prolonged standing is often defined as spending 50% or more of a shift in an upright posture (Andersen et al., 2007; Tomei et al., 1999), this is not based on objective measures. Furthermore, the amount of activity permitted in time 'standing' is not defined or consistent. The use of objective measures of activity in the work place would provide an understanding as to the level of exposure to standing at work and the variances between occupation roles. It is also suggested to be important to consider patterns of activity, as well as overall exposure to standing (Coenen et al., 2016), with indications that breaking periods of standing up with other activities can reduce discomfort (Balasubramanian et al., 2009).

Triaxial accelerometers are commonly used to objectively define activity (Bonomi et al., 2009; Mathie et al., 2004; Parkka et al., 2006) and have been used to measure activity over a working day (Neuhaus et al., 2014). They have been reported to be particularly good for day-to-day activity classification as they react quickly to activity changes and reflect activity better than other sensors such as 3D magnetometers and physiological sensors (Parkka et al., 2006). One example of a commonly used device is the activPAL. Worn on the thigh, the activPAL has been shown to be a highly valid and reliable device to assess posture and motion in both real-world and controlled conditions (Berendsen et al., 2014; Grant et al., 2006) and is the gold standard for measuring sedentary behaviour, i.e. distinguishing between upright and non-upright activies (Kozey-Keadle et al., 2011).

Initial studies using triaxial accelerometers in the workplace have investigated total time spent sitting, standing and walking (Lunde et al., 2017; Nielsen et al., 2017). In these studies, blue collared workers were found to spend on average 2 hours per working day standing statically (Nielsen et al., 2017), healthcare workers to spend 29% of their shift time standing and construction workers to spend 32% of their shift time standing (Lunde et al., 2017). Relationships between activity and injury risk were reported, with greater periods of walking found to be protective from low back pain in blue-collared workers (Nielsen et al., 2017), and greater periods of sitting in healthcare workers shown to be protective in a prospective study (Lunde et al., 2017), but neither study found conclusive evidence relating to prolonged standing (Lunde et al., 2017; Nielsen et al., 2017). However, there is scope to improve our understanding of standing by considering additional work-place activities and focusing on other variables alongside total time, such as patterns of activity.

Therefore, this study has the following aims: to use accelerometer-based activity monitoring to define a more extensive range of upright work-based activities than standing and walking; and to objectively explore if there are differences between two ‘standing’ occupations.

Method

This study consisted of two parts:

1. **Defining activities**
2. **Recording work place activity**

Both parts to this study used the activPal™ activity monitor, collecting at 20 Hz. This monitor was worn on the left thigh approximately 1/3 way between the hip and knee. When standing, the x-axis measures acceleration in the vertical plane, the y-axis in the frontal plane and the z-axis in the sagittal plane. University ethical approval was given (HSCR 16-09) and all participants gave written informed consent.

Part 1: Defining activities

Data Collection

This part aimed to identify work-based activities and to define them using measurements of known activities. The study used 11 participants (male: 9; female: 2), a convenience sample of volunteers from an office environment. The following activities were first identified from work place observations:

Static standing – both feet on the ground, no activity.

Weight Shifting – both feet remain on the ground, but weight is shifted between feet.

Shuffling – sideways activity in which feet leave ground but does not move the body forward. Activity is smaller than a walking step.

Walking – Full steps taken in a forward direction

Sitting –Thighs parallel to the ground and torso upright

Participants performed each of these activities separated by periods of static standing to enable the identification of each event (Table 1). The participant stood in front of a kitchen work surface with a height 0.9m, reflective of standard work surface height measured in kitchens. Instructions were given to look straight ahead, stand tall and place their arms out to the side as far as they could, whilst maintaining contact between their hands and the surface. Tape was placed at the end of their reach. Two pieces of tape were placed laterally on each side to this mark, at 15cm (first tape piece) and 30cm (second tape piece). These distances were selected through piloting as they forced the participants to complete movements that reflected those observed in real environments. Setting the initial distance at the end of their reach accounted for anthropometric differences. Weight shifting and shuffling movements were defined as sideways movements rather than forwards/backward movements as this mirrored real-life tasks that were primarily performed at a work surface. The activPal™ monitor was attached to the thigh and data was collected as described (Table 1).

[Table 1 near here]

[Figure 1 near here]

Data Analysis

The raw acceleration data was extracted for each of the participants performing the known activities (n=11). These give a range of uncalibrated numbers ranging from 1-254 where 128 is considered about 0g and 172 about 1g (9.81 ms^{-1}). Raw data was imported into a custommade MATLAB (2016b) program that enabled the researcher to identify the start and end of each event. An example of the raw data can be seen (Figure 1).

Vector magnitudes were calculated for all axis combinations (xy, xz, yz, xyz), for example:

$$Vector\ Magnitude\ xyz = \sqrt{x^2 + y^2 + z^2}$$

Variable window lengths were tested to determine the most appropriate length for the final model. Smaller window lengths are expected to provide more accurate information, but the data held in longer windows may be more meaningful for classifying activity (Bonomi et al., 2009). The window sizes used were: 1, 2, 4 and 6 seconds. Longer durations were not considered as previously it has been shown that activities in a standing work environment lasted on average 7 seconds (Messing and Kilbom). For each window, the standard deviation and mean were calculated for each variable. The mean of the data contains information regarding the orientation of the device and the standard deviation has a consistent relationship with activity intensity (Long et al., 2009).

A decision tree was developed in 2 steps, as previously described (Parkka et al., 2006). First, the feature selection and nodes were developed from *a-priori* knowledge of the work place activities alongside visual signal inspection. It contained 5 leaf nodes and 4 binary decisions (Figure 2). Secondly, a leave-one-subject-out cross-validation approach was used to identify the threshold values using a custom MATLAB program. The threshold value, accuracy (average percentage of correctly identified activity segments over the entire cross-validation segment), sensitivity and specificity were calculated for each segment. The average of the 11 threshold values was taken as the final threshold value, reflective of previous methods (Bonomi et al., 2009). The 11 values for accuracy, sensitivity and specificity were also averaged to give the final value. This was completed for each of the 4 window lengths.

As the accuracy of the decision trees using window lengths of 2 and 4 seconds only varied by 0.6%, the 2 second window was chosen for the final model (Table 2). The improved information accuracy regarding short movement periods, would be expected to outweigh this accuracy difference, as previous research in a prolonged standing environment found most activities to be short, e.g. 56% step sequences only lasting 1-2 steps (Messing and Kilbom, 2001).

Part 2: Workplace activity

Data Collection

This aim of this part of the study was to record participants activity in a work-based setting and determine if the activity classification developed in part 1 could distinguish differences between job roles classified as ‘standing’. The activity of office workers was recorded as a control comparison. These office workers did not have access to standing desk facilities.

Participants were recruited by contacting work-based establishments (veterinary practices and restaurants). Study information was distributed through employers and employees contacted the primary researcher if they wanted to take part. The sample was a convenience sample, reflecting the spread of people who volunteered at each recruitment site. In total, there were 26 participants (chefs: n=10, veterinary surgeons: n=7; office workers: n=9).

The participants were given instructions to place the device directly onto their skin, in the centre of the thigh approximately 1/3 of the way between the hip and knee, with the figure on the device standing upright. When the participant was not immediately attaching the device, written instructions with a diagram were left. Participants were asked to wear the activPAL for a full work day only, removing at the end of their shift to ensure that all the data was collected whilst the participants were working. If the start and end time of shifts were known prior to data collection, the activPAL was programmed to start and stop collecting accordingly. All participants recorded the start and end of their working hours, so data could be cropped if necessary. Data was collected continuously throughout the shift, including during any breaks that were taken.

Part 2: Workplace recording

Data Analysis

If necessary, data was cropped to the start and end time of the work shift. Data was analysed using the final decision tree (Figure 2), with a 2 second window. A custom MATLAB program split the data into 2 second windows, calculated the mean and standard deviation for the necessary variables and determined which activity was represented in each 2 second window frame.

The activities included those previously defined: sitting, static standing, weight shifting, shuffling and walking as well as time upright, which was the combined time of all activities spent on their feet (static standing + weight shifting + shuffling + walking). An event was defined as the period over which a single activity was performed continuously. The following variables were calculated: total overall time spent in each activity (%); length of each event (s); number of events per hour and the maximum event time (s). The average was calculated for each participant and the overall average for each occupation.

The data from the activPAL was also analysed using the activPAL processing software (activPAL™ v7.2.32). This software produces information about time spent sitting, standing and stepping and has been previously validated and found to have excellent accuracy for these activities when compared to visual observation and other accelerometer-based devices (Godfrey et al., 2006; Ryan et al., 2006; Berendsen et al., 2014; Grant et al., 2006). The overall percentage times spent in each activity were compared to our results, to provide a basic assessment of real-world accuracy.

Statistical Analysis

Statistical analysis was completed using SPSS (v23, IBM). Each variable was tested for normality using a Shapiro-Wilk test. If variable showed a normal distribution ($p>0.05$), one-way ANOVA tests with Bonferroni post hoc tests were used to determine differences between occupation roles. If a variable was not normally distributed ($p<0.05$), a Kruskal Wallis test with Dunn's post hoc tests and Bonferroni corrections was used.

A paired t-test was used to assess differences between the activPAL processing software results and the results from our classification for walking, sitting and standing for all participants grouped together. Alpha level was set at 0.05 for all tests.

Results:

All participants reported shift lengths of 8-12 hours although the duration that the activPAL device was worn for varied and was sometimes less than 8 hours (Figure 4).

% Time per activity

One-way ANOVA results revealed a main effect of occupation for percentage time spent in each activity (Table 1). Average time spent sitting was significantly lower for chefs (14%) and veterinary surgeons (29%) in comparison to office workers (71%). Veterinary surgeons spent a significantly greater portion of time standing statically (44%) compared to chefs (20%) and office workers (16%). Of upright time, chefs split their time amongst static standing (23%), weight shifting (29%), shuffling (23%) and walking (25%), whereas veterinary surgeons spent 62% of their upright time standing statically (Table 3). Individuals varied in time spent upright, as well as the patterns in their upright activity (Figure 4).

Within each occupation there existed variation in % time per activity between individuals (Figure 3). For chefs, upright time ranged from 72-97% and for veterinary surgeons this ranged from 44-95%. Static standing ranged from 15-31% for chefs and from 20-70% for veterinary surgeons. For chefs, time spent walking ranged from 6-31%, weight shifting from 19-31% and shuffling from 11-35%. For veterinary surgeons walking ranged from 2-8%, shuffling from 5-12% and weight shifting from 9-26%.

[Figure 3 near here]

Maximum event time

There was no significant difference in the maximum event time for walking between occupations, with an average 1.6 minutes across all occupations. A main effect of occupation was found for sitting, weight shifting, shuffling and upright time. The maximum event time sitting for office workers (45.7 minutes) was greater than that for chefs (18.5 minutes). For upright time, chefs (78 mins) and veterinary surgeons (103 mins) displayed greater maximum event time compared to office workers (23 mins). Maximum event time weight shifting, and shuffling were greater for chefs (0.7mins, 0.4 mins) than either veterinary surgeons (0.3 mins, 0.2 mins) or office workers (0.5 mins, 0.2 mins).

[Table 2 near here]

Number of events

There was no significant main effect of occupation on number of events per working hour of upright time or time sitting. The number of static standing events per hour was greater for chefs (120) and veterinary surgeons (124) than office workers (41). The number of weight shift events per hour was significantly different for each occupation, the highest number was seen for chefs (232), then veterinary surgeons (156), and office workers (60). There was a significant main effect for number of shuffle events per hour and number of walking events per hour, with chefs having greater values than vets and office workers.

Average event time

The average event time was very low for all occupations (Table 3). There was a main effect of occupation on average event time sitting, with lower values for chefs and veterinary surgeons (1 minute and 3.5 minutes, respectively) than office workers (8.4 minutes). Average event time standing was lower for chefs (0.1 mins) than office workers (0.2 mins). Average event time upright was greater for veterinary surgeons (12.6 mins) than office workers (2.5 mins). There were no main effects for the average event time spent walking or shuffling.

[Figure 4 near here]

[Table 3 near here]

Comparison to ActivPAL software

The t-test results found no difference between our model and the activPAL software for percentage time sitting (activPAL software: 37.8±29.8%; our average: 37.3±28.9%; t_{25}=0.521, p=0.607, CI=-1.5-2.5%) or walking (activPAL software: 12.4±10.8%; our average: 13.1±11.4; t_{25}=0.540, p=0.594, CI=-2.1-3.5%), but did find a difference between the two for standing (activPAL software: 49.1±24.0 our data: 25.3±16.0; t_{25}=7.161, p<0.001, CI=16.9-30.6%).

Discussion

This study has demonstrated for the first time that it is possible to further define standing into static standing, shuffling and weight shifting using a body-worn device to get a more in depth understanding of the activity performed in ‘prolonged standing’ occupations. Using this information, it has been identified that occupations that spend similar lengths of time upright can vary substantially in activity.

There is currently no set definition for prolonged standing, with some studies having a cut off at 50% of the working day (Andersen et al., 2007; Tomei et al., 1999), others 75% (Tüchsen et al., 2005) and observation studies reporting 62-80% time standing (Capodaglio, 2017; Messing and Kilbom, 2001). The activity allowed in the 'standing' time also varies between studies, with examples including being confined to an area of 1 m^2 (Tomei et al., 1999), defining it as 'time spent in static posture' for the lower limbs (Capodaglio, 2017) and one even allowing walking (Tüchsen et al., 2005). This variation, or lack of definition of standing, could have contributed to previous research not finding a clear association between standing and musculoskeletal disorders (Lunde et al., 2017; Nielsen et al., 2017). Recording a greater range of standing activities, as in this study, would decrease the uncertainty regarding the definition of standing and provide a greater level of detail regarding activity in the work place. This is important as variations in how dynamic a standing task is result in differences in leg muscle fatigue and discomfort (Balasubramanian et al., 2009).

The activPAL software has previously been reported to be reliable for identifying sitting, standing and walking (Berendsen et al., 2014; Godfrey et al., 2007; Grant et al., 2006; Ryan et al., 2006). The comparison between the percentage time spent in each activity demonstrated no significant differences for sitting and walking, with average differences between the two of 0.5% and 0.7% respectively, but a large, significant difference between time standing (24%). This suggests that the shuffling and weight shifting movements identified replaced those that are classified as standing by the activPAL software. Therefore, the definition for standing encompasses a range of static and more dynamic activity, that when divided into more specific activities, allows us to determine differences between two 'prolonged standing' jobs.

For the small samples investigated in this study, there was no significant difference between the time spent in an upright posture by veterinary surgeons and chefs. On average, they spent 71% (veterinary surgeons) and 87% (chefs) of their time in an upright posture, with shifts lasting 8-12 hours. Veterinary surgeons spent 62% of their upright time standing statically whereas chefs were more dynamic, dividing their time between static standing, walking, weight shifting and shuffling. The average length of standing, weight shifting and shuffling events for both occupations were short at about 6 seconds, similar to the 7 seconds average standing time previously reported in observations of sales and kitchen personnel (Messing and Kilbom, 2001). It is possible that the differences in work-place activities between veterinary surgeons and chefs could promote differences in injury risk, as standing with periods of dynamic movement have been shown to reduce leg muscle fatigue and discomfort in comparison to static standing (Balasubramanian et al., 2009). In comparison, office workers spent an average 71% of their time sitting, which is reflective of the 66-69% previously recorded with the activPAL device (Oliver et al., 2010; Ryan et al., 2011).

The limited knowledge available regarding work place musculoskeletal disorders for chefs and veterinary surgeons suggests musculoskeletal disorder prevalence is high (Anderson et al., 2017; Haukka et al., 2006). An exploratory interview study reported 13 of the 14 veterinary surgeons and chefs interviewed suffered from aches/pains whilst at work and that workers associated this with working long hours, standing and walking (Anderson et al., 2017). In 495 female kitchen workers, a 3-month prevalence rate of any musculoskeletal disorder was reported at 87%, with 50% reporting problems in the lower back (Haukka et al., 2006). This high prevalence is not surprising based on the results of this study. The amount of time veterinary surgeons and chefs are on their feet for is greater than the 50% time which has been prospectively associated with a 1.9 (CI=1.2-3.0) fold increased risk of suffering from low back pain and a 1.6 (CI=1.2-2.3) fold increased risk of suffering from pain in any region (Andersen et al., 2007). Both professions also recorded periods of more than an hour on their feet at one time, which exceeds the suggested ‘safe’ exposure time of 40 minutes to prevent the development of clinically relevant levels of low back pain in pain developers (Coenen et al., 2017). The high prevalence of musculoskeletal disorders in this population combined with the knowledge they are exceeding activity levels associated with risk of musculoskeletal disorders suggests research should focus on work-place solutions to reduce this risk.

Chronic cardiovascular problems are also high in standing populations, including chronic venous disease and heart disease (Tüchsen et al., 2005; Smith et al., 2017). One study reported the risk ratio for hospitalisation caused by varicose veins in those who stood for 75% of their working day was 1.85 for men and 2.63 for women compared to employees who stood for a lower proportion of time at work (Tüchsen et al., 2005). With chefs and veterinary surgeons in this study spending an average of 87% and 71% of their time on their feet respectively, both professions could be at an increased risk of cardiovascular diseases. Although introducing periods of walking to standing tasks has been shown to reduce discomfort (Balasubramanian et al., 2009), we do not know if greater periods of weight shifting or shuffling at work would offer similar protection against discomfort or be dynamic enough to reduce the venous blood pooling that occurs as a result of the low venous muscle pump action associated with static standing. Therefore, future work should assess the impact of these newly identified standing activities on risk factors for cardiovascular as well as musculoskeletal problems to determine the relevance of them.

The large variability between individuals of the same profession is likely a reflection of the different job roles captured in this study, as well as different establishment sizes and for veterinary surgeons, a range in the type and duration of each surgical procedure performed on the day of collection. There was a range of roles amongst the kitchen staff recruited, from chef-de-partie and commis chef to head chef. Kitchens also varied in size, which would have impacted the distance walking between regions. Therefore, this study has also identified a potential need to identify the impact of job roles within each occupation on activity because with time on their feet varying 25% between chefs and 51% between veterinary surgeons, it is possible that this could have an impact on risk factors associated with prolonged standing.

There were some limitations to this study. The defined activities did not include every activity, for example stair climbing was not differentiated from walking and activity transitions were not included e.g. sit to stand were not identified. However, due to their very short duration these would not be expected to have much impact on results. Participant numbers were small due to the exploratory nature of the study, therefore perhaps not generalisable to wider populations of kitchen or veterinary workers. However, the identification and analysis of the activities identified here would be expected to be translatable to a greater population and those in varying standing roles. Future work should continue to understand differences in work-based tasks between occupations with larger cohorts and to associate objectively measured work-place activity with the risk of developing musculoskeletal or cardiovascular problems. This could enable the development of optimised work-place solutions, be it through exposure limits, footwear or ergonomic workplace development. Furthermore, considering different roles within each occupation may identify certain job roles or tasks that are more damaging to our bodies. It is expected that the activities defined in this study and the analysis technique are generic movements that could be used to categorise movement in more depth for any standing occupation.

In conclusion, we have defined a new range of standing work-based activities, and for the first time identified the ability to classify these activities using a body-worn device in a real-world setting. As far as the authors are aware, this study also provides the first objective measure of activity for veterinary surgeons and chefs and the newly defined activities allowed us to identify differences in standing activities performed by chefs and veterinary surgeons, despite similar times in an upright posture. This suggests that future research should be more detailed in their definition of ‘prolonged standing’ and aim to determine relationship between these work-based activities and injury risk.

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Table 1: Description of activities in order performed by each participant in Part 1: defining activities

Activity	**Length of time (seconds)**	**Description**
Sit	60	Sat still on a chair – thighs approximately parallel to ground
Stand	60	Stand still looking forward, instructed not to fidget or move
Weight Shift	60	Reaching to first tape mark on counter at 70 bpm. Instructed to keep feet on floor.
Stand	15	-
Shuffle	60	Reaching to second tape mark on counter at 60 bpm. Permitted to move feet.
Stand	15	-
Walk	60	Continuous walking with no sharp turns.

Table 2: Development of custom decision tree. Accuracy, sensitivity and specificity of decision tree of each window length.

Variable	Activity	Activity Length (s)			
		1	2	4	6
Overall accuracy (%)		93.29	96.21	95.62	96.80
Average Sensitivity		0.98	0.99	0.99	0.99
Average Specificity		0.93	0.96	0.96	0.97
Sensitivity	Sit	1.00	1.00	1.00	1.00
	Stand	1.00	1.00	0.99	0.99
	Weight shift	0.96	0.97	0.97	0.97
	Shuffle	0.97	0.99	1.00	1.00
	Walk	1.00	1.00	1.00	1.00
Specificity	Sit	0.98	1.00	1.00	1.00
	Stand	0.99	0.98	0.96	0.97
	Weight shift	0.83	0.86	0.84	0.88
	Shuffle	0.87	0.98	0.98	0.99
	Walk	1.00	0.99	1.00	1.00

Table 3: Results of all activity variables with statistical results for all occupations. KW= Kruskal-Wallis test. Post hoc results: [o]=significantly different to office workers (p<0.05) [v] = significantly different to veterinary surgeons (p<0.05) [c]= significantly different to chefs (p<0.05).[8]

Variable	Activity	ANOVA/ Kruskal-Wallis Results			Means and Post hoc results								
					Chef			Vet			Office		
		F	P	partial η^2	mean	std		mean	std		mean	std	
% time	sit	$F_{2,23}$= 43.46	<0.001	0.79	12.9	7.9	o	29.2	19.0	o	70.8	14.4	cv
	stand	$F_{2,23}$= 13.19	<0.001	0.53	20.4	6.4	v	43.9	15.9	co	16.3	11.5	v
	weight shift	KW	<0.001	-	24.9	3.7	o	15.1	6.4		7.8	6.7	c
	shuffle	$F_{2,23}$= 40.53	<0.001	0.78	20.3	6.5	ov	5.8	2.9	c	3.3	1.8	c
	walk	$F_{2,23}$= 30.39	<0.001	0.73	21.5	8.0	ov	5.6	2.5	c	4.0	2.5	c
	upright time	$F_{2,23}$= 43.46	<0.001	0.79	87.1	7.9	o	70.8	19.0	o	29.2	14.4	cv
Max Event Time (minutes)	sit	KW	0.014	-	17.2	18.5	o	31.8	16.1		45.7	23.0	c
	stand	KW	0.051	-	1.8	1.1	o	2.6	0.9		4.0	2.5	c
	weight shift	$F_{2,23}$= 17.85	<0.001	0.61	0.7	0.2	ov	0.3	0.1	c	0.5	0.1	c
	shuffle	$F_{2,23}$= 8.88	0.001	0.44	0.4	0.1	ov	0.2	0.1	c	0.2	0.1	c
	walk	KW	0.088	-	1.6	1.1		1.3	1.0		1.8	3.9	
	upright time	$F_{2,23}$= 10.43	0.001	0.46	77.8	39.1	o	102.9	50.9	o	22.9	12.2	cv
Number of events/ hour	sit	KW	0.513	-	8.0	3.6		6.7	6.5		7.9	5.2	
	stand	$F_{2,23}$=21.75	<0.001	0.65	120.0	24.3	o	124.2	44.7	o	41.4	18.7	cv
	weight shift	$F_{2,23}$=48.47	<0.001	0.81	232.3	33.5	ov	155.8	55.4	co	59.6	25.1	cv
	shuffle	$F_{2,23}$=62.79	<0.001	0.85	214.4	49.6	ov	77.8	28.3	c	37.4	18.7	c
	walk	$F_{2,23}$=69.85	<0.001	0.86	127.4	30.4	ov	33.2	14.9	c	20.4	10.9	c
	upright time	KW	0.499	-	8.1	3.6		6.7	6.5		7.8	5.2	
Average Event Time (minutes)	Sit	$F_{2,23}$= 9.53	0.001	0.45	1.0	0.5	o	3.1	1.4	o	8.4	6.2	cv
	stand	$F_{2,23}$= 14.76	<0.001	0.56	0.1	0.0	o	0.2	0.1		0.2	0.1	c
	weight shift	$F_{2,23}$= 3.75	0.039	0.25	0.1	0.0		0.1	0.0		0.1	0.0	
	shuffle	$F_{2,23}$= 2.93	0.073	0.20	0.1	0.0		0.0	0.0		0.1	0.0	
	walk	KW	0.909	-	0.1	0.0		0.1	0.0		0.1	0.0	
	upright time	$F_{2,23}$= 5.70	0.01	0.33	8.2	4.6		12.6	10.2	o	2.5	1.1	v

Figure 1 – Example of raw activity monitor data collected in Part 1: Defining activities

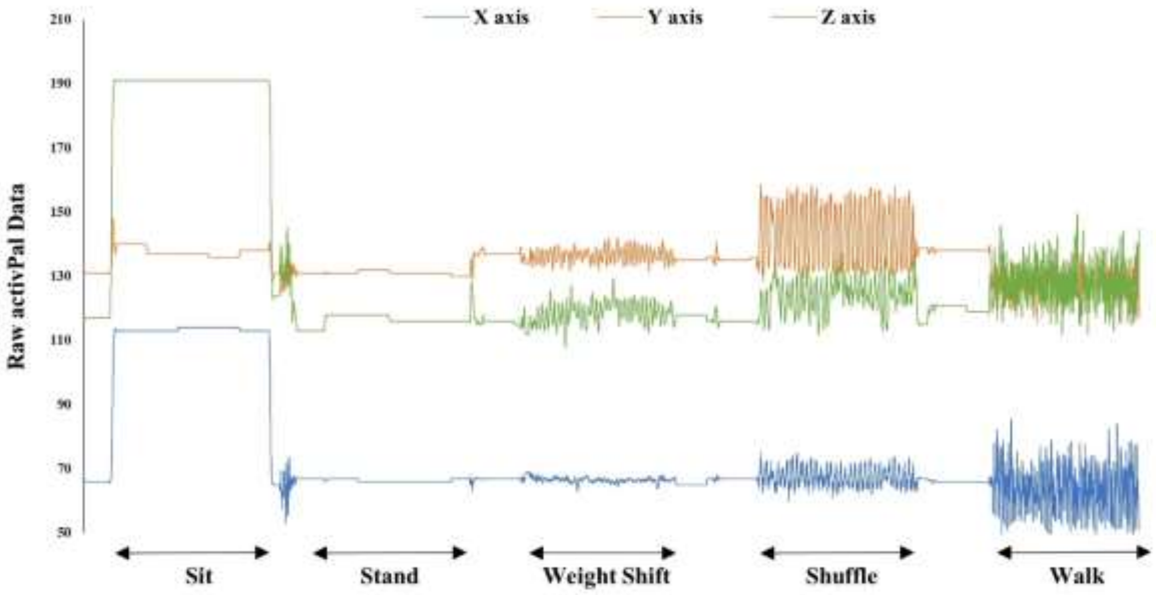

Figure 2: Final decision tree for activity classification. $\bar{a}$ = mean, σ = standard deviation. Subscript letter represents the axis. E.g. $_x$ refers to x axis.

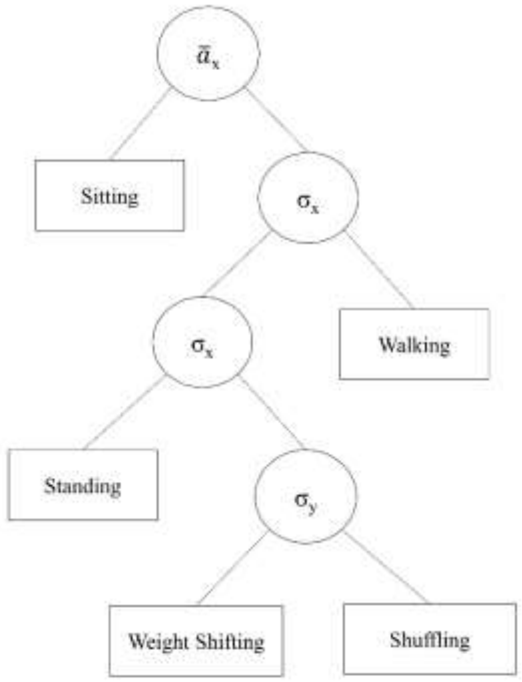

Figure 3: Average percentage time spent in each activity for each occupation. Solid bars represent single participant. Background colours show average for each occupation.

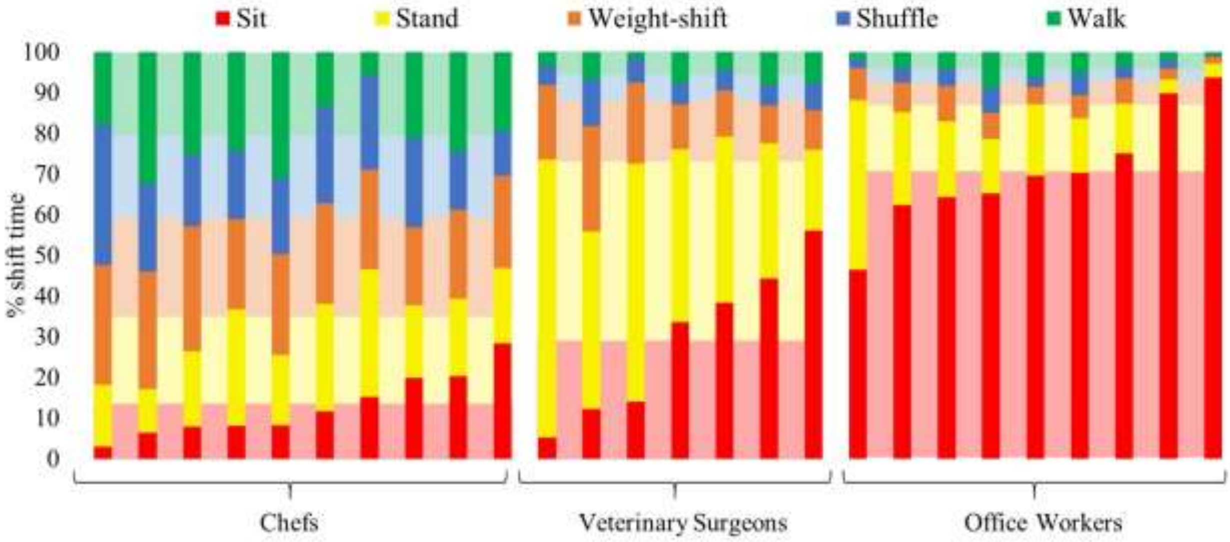

Figure 4: Time spent upright (yellow) and time spent sitting (red) for each participant. The 0 at the top of each circle represents the start of each shift